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13. ABSTRACT (Maximum 200 words)  The purpose of the Environmental Knowledge Base (EnvKB) project is to reduce the environmental impact of facilities by providing to Designers, Operators, and Builders, environmental impact assessments and considerations during their design and decision making process. The EnvKB project consists of three different but related products - Designer EnvKB, Operator EnvKB, and Builder EnvKB. Each software tool interacts with a different user. First year efforts have focused on the Designer EnvKB and have produced a Phase II prototype, initial beta, second beta, and final beta version. The final beta version contains the ability to produce relevant design considerations, similar cases of good environmental design, environmental impact evaluations, and a design process map. Designer EnvKB primarily lacks material environmental information with which to generate evaluations, and design features with which to generate relevant design considerations along with the associated cases. These shortfalls will be addressed in the second year with increased data entry. Second year activities will also include the development of Operator and Builder versions.				
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# **Environmental Knowledge Base Project**

## **Phase II First Year Report**

by

**Dick Stottler,  
Stottler Henke Associates, Inc.**

**March 31, 1995**

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## 1.0 Introduction

Interest in protecting the environment has grown in recent years. One major factor affecting our nation's environment is often ignored - the buildings and facilities in which we live and work. The environmental impact is felt throughout the entire life-cycle of a building from materials acquisition, through construction/installation, use and demolition. The environmental effects are both global, in terms of resource depletion, greenhouse gas emission and ground water pollution, and local, in terms of habitat destruction and indoor effects on occupants. Specifically, acquisition of building materials may result in resource depletion, production of toxic wastes, greenhouse gases, etc.. Construction of a building generates wastes such as concrete which end up in landfills and may be as high as 20% of the total materials used. Installation of carpeting and other flooring, and painting of the indoor and outdoor walls creates harmful emissions. During a building's use, occupants may suffer from exposures to chemically treated materials. When a building is demolished, much of the debris is transferred to a landfill. In fact, 10 to 30% of the space in landfills is composed of building debris, making it second only to paper in many locations.

The environmental impact of facility design, construction, use and demolition has not been adequately acknowledged or addressed until now. There are currently few government regulations relating to the environmental effects of building design and use. At the local level, communities can be involved in home recycling efforts, but it is more difficult to apply pressure locally to promote green building design because many construction projects are independently financed. Building construction is generally considered to have a one-time impact on the environment and little attention is paid to the effects of routine maintenance of the facility. Because many people spend up to 90% of their time indoors, either at work or at home, the health effects on building occupants and the ensuing liability and cost for cleanup are reasons enough for devoting attention to this problem.

Unfortunately, facility designers, builders and operators do not currently have a convenient, well-grounded means of considering environmental issues during design, construction and building use. Throughout the facility life-cycle (design, construction, operation and renovations, and demolition), decisions are based primarily on initial and operating costs. Environmental factors are not generally considered, partly because environmentally related data are not readily available to facility designers and managers. This environmental data includes the detrimental effects of energy and resource use, by-products, and the environmental effects caused by the existence of the material. These detrimental effects can be caused during fabrication of the building materials and systems, the incorporation of the materials and systems into the building during construction, the existence of those materials and systems in the building during its useful life, the maintenance required by or renovations involving those systems or materials, and the disposal of those materials and systems after the useful life of the building has ended.

With the current environmental awareness and good will throughout the country, facilities designers have indicated a willingness to take environmental considerations into account and consider it a marketing benefit, if the environmental information was readily available to them in a form that they could easily use.

What is needed is an automated, environmental, knowledge-based model for facilities design, operation, and construction. To achieve acceptance it must be designed and implemented in close cooperation with the end-users - facilities managers, designers, and general contractors. It must include the adverse environmental effects of building materials, systems, and processes across the entire life-cycle of the building. It must present its information in a way that facilities designers, managers, and contractors can accept and use.

In Phase I, Stottler Henke Associates, Inc. (SHAI) working with the U.S. Army Construction Engineering Research Laboratory (CERL) and the Environmental Protection Agency (EPA), proved that environmental information can be acquired, represented and used. Using advanced Artificial Intelligence (AI) and Object-Oriented software technology, SHAI developed a prototype system called the **Prototype Environmental Knowledge Base System** which evaluates the environmental impact of building materials, taking into account issues such as natural resource depletion, hazardous wastes and emissions to produce the material; the exposures caused by the material on building occupants; and whether the material can be recycled or must be land filled. The environmental impact is presented to the designer in a clear, easy-to-understand form. Alternative materials can be compared to allow selection of the most environmentally friendly material. Alternative systems and buildings can also be evaluated. The prototype can even suggest more environmentally friendly design alternatives for possible consideration by the architects and engineers.

The Phase II effort we proposed was to develop a full-scale **Environmental Knowledge Base System (EKBS)** which would expand upon the Phase I work and allow designers to easily respond to the growing environmental movement. The system would capitalize on the current environmental awareness, allow the marketing of green designs, and reduce the liability from sick building syndrome and actions by environmental groups.

The Phase II EKBS would aid facility designers, managers, and contractors in considering environmental factors when making design and operation decisions. A facility designer could get a description of the environmental effects throughout the life cycle of the building's materials and processes. The designer could then compare environmental effects as well as cost when considering different options. Environmentally sound alternatives could also be suggested by EKBS.

The contractor could view the environmental effects of different processes required to construct the building, and receive environmentally sound suggestions. For example, an alternative type of glue might be recommended to improve IAQ during building life.

The facilities manager could view environmentally related data in deciding upon furnishings, operation and maintenance procedures, renovations, and building demolition. By presenting detrimental environmental effects, costs and alternatives, the facility manager can make better decisions throughout the life cycle.

## **2.0 Work Performed**

There were several tasks performed during the first year of the Phase II work. Each task is described below with a roughly chronological ordering of the work performed.

### **2.1 Knowledge Gathering of Literature and Software Review**

SHAI has gathered dozens of documents for this project. We have performed automated literature searches through different computer systems including the Internet and University of California systems. Additionally, we have obtained references from the several experts whom we have contacted as well as from CERL. Our reference list is available upon request.

We have also investigated several relevant software packages. These include the Harris Directory, EcoSmart Home, ECOSYS, Greening of the White House and Greening of America, National Park's Green Product Guide, and three software tools which implement the analytical hierarchy process for LCA recommended by NIST to ASTM as a proposed standard - Criterium Decision Plus, Expert Choice 8.0, Logical Decisions.

### **2.2 Knowledge Gathering from Experts**

We have spoken to several experts in the environmental design field. At the beginning of the project we spoke with Hal Levin, John Clark, Raymond Cole (BEPAC), and Barbara Allen of the University of Southwestern Louisiana who was compiling a comparison matrix of building materials. We then interviewed Thomas Hines (ECOGROUP), designers from Flack & Kurtz, and John Carter. We visited the EPA Office of Solid Waste. Later we interviewed John Picard, Jan Johnson, Karen Docksetter, Julia Russell, and Larry Wolff. We had several discussions with Lawrence Berkeley Laboratories which included Steve Selkowitz, Konstantinos Papamichael, and with representatives of CIFE, who has implemented many of LBL's concepts. CIFE contacts included Paul Teicholz and Mark Clayton. We then proceeded with discussions with Bill Van Erp, Anthony Bernheim, Clark Bisel of Flack & Kurtz, and Henry Taylor.

### **2.3 Requirements Definition**

In October of 1993, we were in contact with about 20 design professionals from local firms as well as larger national firms, to directly discuss issues that will be relevant to the software design. Our goal for these discussions has been to gain a more thorough understanding of the design processes that designers follow, to see how much they currently consider environmental factors, to get feedback from them on the general concept of the full-scale system, and to hear what features they would find most useful, and what kinds of input and output would be most practical, efficient, and clear. These meetings have been quite useful, because they provide an indicator of what kind of system architects would actually use. We have gotten general opinions from those we have



spoken to, along with specific suggestions, ranging from reactions to features of the Phase I prototype, to new ideas for the next development stage.

In December of 1993 we talked to design professionals in Washington, D.C. We talked with local architect Clare Malone who has compiled her own environmental resource information, and Dr. Kazmierczak who is an engineer working on mostly federal projects. Additionally, we analyzed the specifications and drawings and programming produced at each phase of the design process. These documents have been very useful because they contain the actual results of each design phase, which sheds a great deal of light on the entire design process. Materials decisions of varying specificity are made throughout the design phases, and it is very helpful to know how much detail is specified at each stage of the design development.

We also demonstrated the Phase I prototype to several designers for feedback. After it was developed we also demonstrated the Phase II prototype to potential users. The initial and second beta versions were sent to designers to demonstrate to themselves; we received those comments back as well. The comments are summarized in the Results Section.

Another part of Requirements Definition was deciding on a hardware platform. Initially we investigated PCs, Macs, Unix work stations, and Intergraph workstations. We also investigate relevant software with which to interface, initially looking at AutoCADD, miniCADD, and Intergraph. We confirmed the requirement of interfacing to AIA's ADEPT (Master Spec) program.

We made a preliminary decision to target EnvKB toward facility designers doing federal work. We also decided that our target hardware platform is 486 IBM compatibles. We would develop two versions - a full Windows implementation and a more limited DOS version callable from Master Specification products and consisting primarily of the impact evaluation and alternative material utilities. We developed a requirements list for a commercial version in May of 1994 and how the Designer EnvKB relates to the operator and builder versions.

We narrowed the CADD choices down to those sanctioned by the DOD - AutoCADD and Intergraph. In August 1994 we chose AutoCADD. Beth Broeker of CERL was instrumental in helping define user requirements. We investigated several energy analysis packages, narrowing the scope to BLAST or DOE-2. We chose DOE-2 because it is most widely used. We chose to interface to MCACES & spreadsheets for cost estimation.

In November of 1994, Shig Fujitani arranged a meeting of several designers to discuss EnvKB from a user perspective. In December, our Human Factors specialists delivered story boards, illustrating their concept for EnvKB. We also received the Design Process Map, which affected user requirements.



One of the important inputs into the Requirements Definition and the EnvKB product in general was to be workshops of users and experts. Much of October, 1993 was spent preparing for workshops scheduled for November. We made several contacts for and prepared a list of attendees, prepared an organizational agenda for the meeting, and prepared a system for effective knowledge gathering and communication for the 50 or so people expected to attend. In May of 1994, we also began preparation for another planned workshop.

## **2.4 Gather Cases**

As the SERDP effort became delayed, we concentrated more on other aspects of the system, including the gathering of cases. We have collected about 30 cases of good environmental design. These have been primarily identified and collected from experts and documents. We also sent out a letter and questionnaire to environmental designers requesting case information. In fact, it is easily a full-time job to collect case information. We have our case list available upon request.

## **2.5 Design Related Tasks**

There were several tasks which were required to support the design process but were not part of the implementation effort. We investigated possible units for environmental impact evaluation output. We produced story boards for the evaluation output, which included different graphical breakdowns of the evaluations. We researched the kinds of design considerations which would need to be represented and addressed. In January of 1994 we developed our first version of the case structure. We surveyed existing environmental impact evaluation algorithms. We redesigned the environmental principle hierarchy. In June, 1994, we expanded the design principles. We acquired and coordinated with human factors psychologists starting in June, 1994. We again expanded the design principles in July 1994. We coordinated with Greg Norris (NIST) regarding LCA.

## **2.6 Designer EnvKB Development**

There were several tasks, spanning the entire first year of effort relating to the development of the Designer EnvKB. We investigated software development tools starting with Kappa-PC, Neuron Data's Nexpert, and several C++ environments.

We have designed a Phase II EnvKB prototype which would be much closer to the commercially released version. It was implemented in March, 1994, and demonstrated to experts and users in May and June. The design included the structures to represent current design projects, cases, design advice, and alternatives as well as supporting object classes for both this advanced prototype and the final version.

The case structure involved a hierarchical ordering of environmental goals or design principles which are applied in specific building cases. The buildings were represented as collections of these principles, along with function, size, location, and building component information. With this kind of representation, the positive aspects of a variety of projects could essentially be merged, producing a more unified and coherent schema for design advice, which arises directly from previous successes. The first building to be represented (partially) in this framework was the National Audubon Society Headquarters in New York City. A second case was soon incorporated into this preliminary case base.

The second generation EnvKB prototype was implemented in March, with a variety of new features and capabilities. The prototype structure mirrors the representational structure for the projects and cases that will be stored and evaluated. Projects and cases have nearly identical structure and editors. The main components of building representations are the materials lists and design principles, along with miscellaneous other information (including location, climate, function, size, floor plans, decision processes). The current prototype includes the interfaces for entering and viewing this information, from which evaluations and recommendations can be produced. In July of 1994 an environmental evaluation algorithm was coded into the prototype.

In February, 1994, we began arrangements with Human Factors psychologists for their input on the final user interface. We identified federally required cost estimation packages as important tools with which to interface. We continued to review several different software platforms for the EnvKB system, including KAPPA PC, Neuron Data's Nexpert Object, and several object-oriented C++ environments. For the full-scale system, our first choice for the development environment was IntelliCorp's KAPPA-PC. We made very favorable distribution arrangements. The standard distribution price for KAPPA-PC was \$450/copy and we had an agreement for \$2/copy. Unfortunately, KAPPA-PC was knocked out of contention because it will not be ported to Windows '95. In October '94, we reopened the investigation of development tools, including Neuron Data's Nexpert, C++, Smalltalk, and Lisp.

We had an informal collaboration with LBL in that we exchanged case representation formats. We developed a functional description of Designer EnvKB in October, 1994. We fully defined the case structure. In November, 1994, we narrowed the list of candidates to individual products within the language groups - Visual C++ (paired with a GUI development system), Digitalk's Smalltalk, Visual Works, and Franz's LISP. In November, 1994, we developed the EnvKB Final Design and chose Digitalk's Smalltalk for most of EnvKB and Visual C++ & WindowsMaker for the environmental evaluation implementation.

In December, 1994, we implemented an internal release of EnvKB. In January, 1995, we implemented the first beta which was released to a small group for comment. In February, 1995, we implemented the second beta which was also released for comment.

and in March, we implemented the final beta of EnvKB 1.0 which is now ready for limited release.

## **2.7 Strategy Meetings**

There were several strategy and other meetings which occurred throughout the first year. The first was at CERL in November 1993. A major decision there was to pursue environmental impacts units of dollars where possible. In Washington, D.C. on January 12, 1994, at the Corps Headquarters, we briefed an interested group about the EnvKB project. We attended the Green Building Conference in February, 1994, and met with CERL, EPA, NIST, NIBS, and AIA. We also prepared and gave a talk at the Pollution Prevention Conference on May 2, 1994. June 8, 1994, Tom Napier visited our offices in Belmont, where he was shown the prototype. His comments were implemented.

In July, 1994, in Santa Cruz, a large meeting was held with the Greenbuild team. They seemed to promote a broader scope - to give a complete environmental picture to a smaller number of users. They stated that it was impossible to produce a single environmental evaluation and that units of dollars wouldn't work. They also raised questions about the target audience.

We participated in a US Green Building Council Roundtable discussion of the Green Building Resource Center in San Francisco. In November, 1994, we attended the Sustainable Construction Conference in Florida. We participated in a December 2nd conference call with SERDP project members. A strategy session was held on January 19, 1995, at CIESIN in Washington, D.C. We were told that no substantial materials information would be received anytime soon. This was not a surprise, since we had been working on other fronts, because SERDP funding was so delayed.

On February 23rd and 24th, 1995, at CERL, a meeting was held with Tom Napier and a conference call was made to James White. It was decided that material data was critical and would not be developed in the near term by the SERDP effort.

## **2.8 Distribution**

We have made tentative distribution arrangements for EnvKB with both the AIA and NIBS. We have investigated different EnvKB startup options including DOS, Windows, AIA's ADEPT, and NIBS's SPECSINTACT. Further distribution arrangements will be made when the product has reached the proper state of readiness as decided by SHAI and CERL.

## **2.9 Operator EnvKB Tasks**

There are several tasks associated with the Operator EnvKB, though its level of effort is much smaller than the Designer EnvKB. We have researched the issues which must be addressed. We have gathered a few documents relating to environmental facility

operations and have some contacts. We have talked with Doug Heinan, first in July and then in February. We have determined that the large majority of the structure and design of EnvKB for Designers is applicable to the EnvKB for Operators. We have implemented a few operator considerations and products and the retrieval of them. We have determined how the Operator EnvKB interface should differ from that of the Designer EnvKB. The Designer EnvKB with the Operations information serves as an Operator EnvKB prototype. The first beta version of the Operator EnvKB will be completed June 30, 1995.

## **2.10 Energy Analysis Software Interface**

We investigated several energy analysis software packages with which EnvKB should interface. The primary goal of this interface was to read in a building's energy consumption profile with which to do an environmental evaluation of the building. The software packages we investigated include DOE-2 and Power-DOE from Lawrence Berkeley Laboratory, BLAST from USACERL, Comply 24 from Gabel Dodds & Associates, Micropass 4 from Enercomp, Cerecode from Ball State University, and EN4M from MC2 Engineering Software. Of these, DOE-2 appears the one which will be most widely used in the future. Even on Corps designs, when BLAST is required, DOE-2 is often used. The DOE-2 interface is described in Section 3. BLAST would be the most logical choice for a second energy analysis program with which to interface. Its inputs, outputs, and method of calculation are very similar to DOE-2.

### **3.0 Results**

There are several results which are described in the following sections.

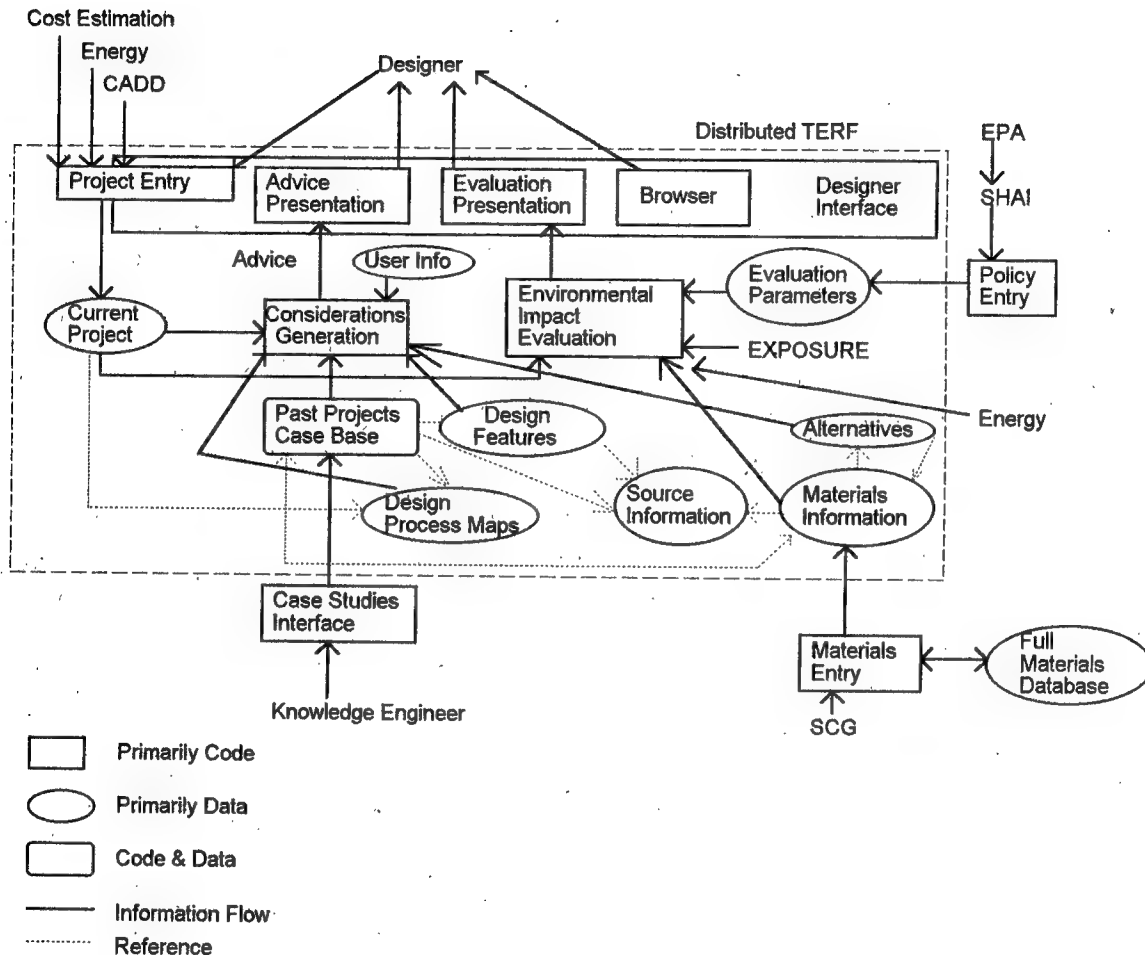
#### **3.1 Feasibility**

The feasibility of the SHAI portion of EnvKB has been proven in several ways. Implementation of two different prototypes and EnvKB 1.0, which includes functionality in all areas, has shown that the software can be created. Furthermore, extensive interviews with users show a strong desire and willingness to use the EnvKB. What remains unproven is the ability of another organization to produce the required material data and environmental expertise. It is currently assumed that quantitative material data will not be available for years, at current funding levels. The availability of qualitative material data is still unknown. CERL is planning a project which should either produce such data or prove it to be impractical.

### 3.2 EnvKB Design

This final EnvKB design was finished in November, 1994. The current implementation differs from it in only minor details.

#### Overall Design



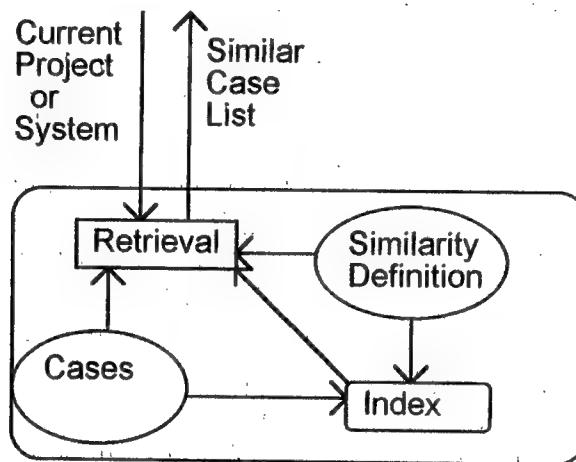
Past Projects Case Base consists of environmentally friendly cases of design. Its design follows. Current Project contains the information on the user's current project. Its structure is a slight modification to the Case Structure Design. Considerations Generator produces relevant design considerations. Its design follows. Design Features are also known as design considerations. Most are referenced by at least one case. Their design follows. Alternatives are more environmentally friendly alternatives to standard building materials and components. Browser allows designers to browse through cases, design principles, materials information, or decision process maps. Materials Information is the environmental impact information associated with building materials. Full Material



Database contains all of the environmental information associated with building materials. It is condensed into a vector of environmental impacts to become the Materials Information. Impact Evaluation performs the environmental impact assessment for a material, component, system, or building.

### Past Projects Case Base

The case base consists of cases of good environmental design, a similarity retrieval mechanism, similarity definitions which control retrieval, and indices to make retrieval more efficient. The case structure was unified with the current project structure and is called the Building Representation.



### BUILDING REPRESENTATION

The representational approach for buildings in general is intended to be applicable to both the case studies which reside permanently in the case base, and the 'queries' or 'current projects' entered by users who are seeking design advice. A major consideration for the development of this structure was the desire to make cases and queries adaptable. For example, a user may seek advice on just a particular materials decision in a particular room, without having to enter a representation for his entire project. Furthermore, the structure is designed so that the user may assemble these fragmentary representations of a project, into a more complete project representation. In fact, the goal was to make this one of the primary means by which users construct their current project representations.

To meet this goal, the representational structure is defined so that cases and queries may range in scope from a single room to an entire facility or project. This is accomplished by making Zones (an extension of the use of zones in DOE-2) the top-level of the structure. Whether a zone represents a single room, or an entire building (with sub-zones), a similar representational structure applies, so all cases and queries are represented as zones. This zone breakdown is implemented in addition to the more standard,

functionally-oriented system breakdown, which provides for compatibility with different user needs. Just as some users may prefer to receive advice only on a particular room or zone, other users may seek advice on a particular system. Because the same materials can be listed in both Zones and Systems, there will be some overlapping data.

The representational structure for buildings is implemented in an object-oriented paradigm. This approach is useful because of the modularity it allows for the process of constructing representations. With a modular, compositional structure, the user can choose the depth and include components of the 'current project' definition, depending on the detail and scope of the advice sought. Classes of objects are defined, which establish the frameworks for the specific information that will be represented in instances of these objects. These classes define attributes which are inherited by instances, and whose values are set to other objects.

Every part of the data is an object, even basic elements like names (String objects) and numeric values (Number objects). The building object structure is described here by showing first the class name (and relevant comment if necessary), then the class attributes, where each attribute is paired with the type of object it will have as a value. For this outline, these deeper classes are described after their initial reference, but low-level details are omitted for many, particularly system primitive objects (String, Number, etc.).

There are two kinds of objects in this implementation: dynamic and library. The dynamic objects are those whose attribute values will be set interactively either by the end user, or by an administrative user (for example, one who is entering a new case). The library objects are predefined data structures that are either used as templates or directly referenced as values in the dynamic objects. For each of these library object classes, a list of the available instances can be retrieved, from which the user can select an appropriate choice.

<u>Class</u>	<u>Attribute</u>	<u>Attribute Object Type</u>	<u>Attribute is Dynamic / Library</u>
<b>CurrentProject</b>			
	Name	String	primitive
	EnteredBy	UserProfile	Dynamic
	Zone	Zones	Dynamic
<b>Case</b>			
	Name	String	primitive
	Zone	Zones	Dynamic
	SimilarityDefinition	SimilarityDefinitions	Dynamic

The CurrentProject class is basically similar to the Case class. The main difference lies in the fact that a CurrentProject functions as a query, or a request for advice. Because the advice that is retrieved should partly be a function of the type of user who seeks advice, the 'EnteredBy' attribute is necessary for CurrentProject objects. Case objects, on the other hand, are the source of advice, so the user profile is not necessary for them.

Both of these classes refer to a building (or zone, or system) through its top-level zone. Additionally, cases can each have a unique similarity definition to over ride the default one. This way, individual cases can decide how their similarity to the current case should be assessed.

<u>Class</u>	<u>Attribute</u>	<u>Attribute Object Type</u>	<u>Dynamic / Library</u>
<b>Zones</b>			
	Project	Projects	Dynamic
	Type	copy of a ZoneTypes instance	Library
	MaterialSpecs	list of MaterialSpecs	Dynamic
	DesignChoices	list of DesignChoices	Dynamic
	Systems	list of Systems	Dynamic
	Details	list of Details	Dynamic
	SubZones	list of Zones	Dynamic

There are a number of reasons why the Zones class is the top-level of a building representation. The idea for the Zones class is for it to be general enough that it can provide the structure for representing systems, rooms, or entire buildings. A system would be implemented in this structure by only filling in the Project, MaterialSpecs, DesignChoices, Systems, and Details attributes, and leaving the rest empty. An individual room would be represented by filling in all attributes except SubZones, and only filling the Systems attribute with systems relevant to the room. This structure will be extended with the addition of a Space attribute, by which the dimensions of the room (or building) can be described. This attribute will refer to a Spaces class. An entire building would be represented by filling in the entire structure, with SubZones too if possible. Whether an entire building, an individual room, or a particular system are being represented, they all share certain basic Project information. In fact, there may be several zones which are part of the same building, so the basic context information for the project can be kept in a single separate object, which is referenced by any corresponding zones or systems.

<u>Class</u>	<u>Attribute</u>	<u>Attribute Object Type</u>	<u>Dynamic / Library</u>
<b>Projects</b>			
	Location	Location	Dynamic
	Renovation?	true / false	primitive
	ConstructionType	ConstructionTypes	Library
	StructureProfile	list of FloorProfiles	Dynamic
	Details	list of Details	Dynamic
	PeopleInvolved	list of Persons	Dynamic
	CurrentDevStage	DesignDevStages	Library
	CompletionDate	Date	primitive
	TotalCost	Quantity (Currency)	Dynamic

The Projects class is almost entirely used for context purposes, in retrieving relevant advice. Some of the attributes are also for general reference and bookkeeping

purposes. As this tool is integrated with different performance modules, including energy, IAQ, and our own environmental evaluation utility, attributes will be added to the Projects class for maintaining this assessment output.

<b>Class</b>	<b>Attribute</b>	<b>Attribute Object Type</b>	<b>Dynamic / Library</b>
<b>Location</b>			
	Longitude	LatLong	Dynamic
	Latitude	LatLong	Dynamic
	Altitude	Quantity (Length)	Dynamic
	UrbanOrRural	UrbanOrRural	Library
	Biome	Biome	Library
	Temperatures	list of Quantity (Temperature)	Dynamic
	Precipitation	list of Quantity (LengthSmall)	Dynamic
	SolarRadiation	list of Quantity (EnergyArea)	Dynamic
	Humidity	Quantity (Concentration)	Dynamic

The Location class is also primarily for context. There are a number of potential additions that could extend this structure, if they become necessary. (1) Adjacent wind / light influences (trees, buildings, hills, reflective surfaces). (2) Adjacent temperature influences (bodies of water, thermal retention / radiation). (3) Adjacent air quality influences (loading docks, busy streets, trash depositories).

<b>Class</b>	<b>Attribute</b>	<b>Attribute Object Type</b>	<b>Dynamic / Library</b>
<b>FloorProfiles</b>			
	Footprint	Detail	Dynamic
	Height	Quantity (Length)	Dynamic
	FloorArea	Quantity (Area)	Dynamic
	NumberOfZones	Number	primitive

The FloorProfiles class is used to give a rough description of a building type, without resorting to 'fuzzy' terms like high-rise. It provides a simple structure for defining the shape of a building, without requiring the detailed coordinate definitions that are necessary for Space classes (see Zones). A potential extension to this class would be a capability to match rough footprint shapes.

<b>Class</b>	<b>Attribute</b>	<b>Attribute Object Type</b>	<b>Dynamic / Library</b>
<b>Systems</b>			
	SystemType	SystemClasses	Library
	MaterialSpecs	list of MaterialSpecs	Dynamic

Systems do not involve space information, which makes their representation relatively simple. For example, an HVAC system weaves through many different zones in a given building. So, the system type and a materials list are sufficient for representing a building's system.

<u>Class</u>	<u>Attribute</u>	<u>Attribute Object Type</u>	<u>Dynamic / Library</u>
MaterialSpecs			
	Material	Materials	Library
	Quantity	Quantity (unit depends on Material type)	Dynamic
	BrandName	MaterialBrandNames	Library
	Motivations	list of Motivations	Library
DesignChoices			
	Principle	(Separate functional module)	
	Motivations	list of Motivations	Library

The MaterialSpecs class and DesignChoices class are both subclasses of a general Decision class, since they share the attribute Motivations, by which the designer or specifier's motivations are represented. This class will be extended as our representational structure is developed, to include an Application attribute, which will represent where and how a decision is applied.

<u>Class</u>	<u>Attribute</u>	<u>Attribute Object Type</u>	<u>Dynamic / Library</u>
Detail			
	Type	DetailTypes	Library
	File	FilePath	primitive
	Source	BibliographicRef	Both

The Detail class is the basic mechanism by which specific details will be stored for presentation to the user. A Detail instance may be text or an image of a variety of formats, and it is designed so that it may potentially be other media as well. The Source attribute will refer to BibliographicRef objects, which will either be created dynamically, or copied from existing references in the Library, so in a sense this object is both Dynamic and Library.

## Other Dynamic Classes

<b>Class</b>	<b>Attribute</b>	<b>Attribute Object Type</b>	<b>Dynamic / Library</b>
UserProfile			
	User	Person	Dynamic
	CurrentQueries	list of CurrentProjects	Dynamic
Person			
	Name	String	primitive
	Address	Address	Dynamic
	Organization	Organization	Dynamic
	Discipline	UserTypes	Library
Organization			
	Name	String	primitive
	Address	Address	Dynamic
	Functions	String	primitive
Address			
	Street	String	primitive
	City	String	primitive
	State	String	primitive
	Zip	String	primitive
	Country	String	primitive
	Phone	String	primitive
	Fax	String	primitive
LatLong			
	Seconds	Number	primitive
	Direction	Direction	Library
Quantity			
	Value	Number	primitive
	Units	Unit	Library
BibliographicRef			
	Reference	String	primitive



## Library objects

Each of the Library objects has an attribute structure which contains further specific information. At a minimum, there is an attribute for the instance name, but some of these classes have other associated information too. These deeper structures are omitted for most of the classes listed here.

Biomes	Initial instances include: Northeast Coastal, Southeast Coastal, Northeast, Southeast, Great Lakes, Appalachians, Gulf Coastal, Mississippi Valley, Great Plains, Rockies, Great Basin, Sierras, Northwest, West Coast, Southwest.
ConstructionTypes	Initial instances include: Steel, Concrete, Masonry, Wood, Straw Bale.
DesignDevStages	Initial instances include: Predesign, Schematic Design, Design Development, Construction Documentation, Construction Administration, Occupancy. This class will be extended to link to the elements of the Decision Process Map module.
DetailType	Initial instances include: Text, Bitmap. These are the kinds of Details that can be presented. As presentation capabilities are expanded, so will the types.
Direction	Instances include: N, S, E, W. (Used in LatLong objects)
EnvFactors	Initial instances include: Recycled Content, Recyclability, Natural Resource Depletion, Habitat Loss, Life Cycle Wastes, Life Cycle Energy Consumption, Longevity. Some of these have sub-factors.
Materials	The in-depth materials information is maintained in a separate data module, so a given Material instance in the building representation library module simply contains its name, and a list of its corresponding BrandNames (of type MaterialBrandNames). There is a preliminary list of Material instances in the library from the cases we currently have.
MaterialBrandNames	Each MaterialBrandNames object contains attributes for the product name, the manufacturer, and distributors.

<b>Motivations</b>	Initial instances include references to the EnvFactors, plus non-environmental motivations such as Availability, Esthetics, Durability, Cost, Installation Ease, Client Requirement, Familiarity, Commonality.
<b>SystemClasses</b>	Instances are related to CSI UniFormat breakdown, with the corresponding levels. At the top level, initial instances include: Substructure, Shell, Interiors, Services, Equipment and Furnishings, Other Building Construction, Building Sitework, and General.
<b>Unit</b>	Unit objects have attributes for display names (as in ft <sup>2</sup> ), type (references to UnitType objects - this is for appropriate conversions), and conversion factors.
<b>UnitType</b>	Initial instances include: Area, Concentration, Length, LengthSmall, Volume, Weight, EnergyArea, Power, Temperature.
<b>UrbanOrRural</b>	Initial instances include: Urban, Rural. Finer distinctions may be added later.
<b>UserTypes</b>	Initial instances include: Architect, ME, CE, EE, ID, Specifier, Construction Manager, Consultant / Specialist, Student / Learner.
<b>ZoneTypes</b>	ZoneType objects represent a type of zone by its use or function, and contain attributes referring to default occupancy templates (ZoneOccTemplates) typically associated with the zone's function. When a Zones instance is assigned a Type, the selected Type is copied to the instance, so that the occupancy schedule can be modified without changing the library instance. Initial instances include: Office, Residential, Factory / Industrial, Storage, Public Access, Garage / Parking, Meeting / Conference, Rest / Sleep, Lounge, Food Preparation, Food Consumption, Entry / Reception, Hallway, Restroom / Bathroom.
<b>ZoneOccTemplates</b>	These are templates for standard occupancy schedules.

## Retrieval

Conceptually, the system evaluates the similarity of every case to the current project. The cases with no similarity are dropped and the remaining ones are sorted in order of decreasing similarity. Each case may have a different definition of similarity or the default can be used. In actuality, the system does not have to examine every case, but can use an index to limit the number of cases to be examined.

## Default Similarity Definition

The default Similarity Definition calculates a Similarity Score by performing a weighted sum of the feature matches and dividing by the sum of the weights. It considers, in roughly decreasing order of importance, Renovation/New Construction, Occupancy type, Size, Structure Type, Location, Design, and Material List.

## **Design Considerations Generator**

The Design Considerations Generator consists of the design considerations (or features) and the relevancy retrieval methods.

## Design Considerations

Designer EnvKB contains a set of environmental design features, most of which are associated with a specific case. Each environmental design feature includes knowledge as to its own applicability to different projects. After the user has entered information on his current project, each design feature is individually assessed for its relevancy to the current project and the most relevant ones are displayed. Each design feature also includes several links. These links connect the feature to other features which aid its goal, to principles it is trying to accomplish, to environmental factors it is addressing, to environmental principles it is in conflict with, to cases which utilize it, and to the sources which described the feature.

The information stored for each design feature includes a title in the form of a suggestion, a description of the feature, the process by which it should be incorporated into the design, the rationale, the environmental factors it addresses and the possible magnitude of that impact, information regarding when the feature is applicable, problems and restrictions associated with the design feature, projects in which it was used, other design features which facilitate this features application, and where in the design process the feature should be considered. The structure is described below, where anytime a plural word is used, more than one value can be present. An example follows.

Title:	One line description.
Goals:	Principles above this one in the goal hierarchy.
Details:	Text or text, picture, or other media files,
Environmental Factors Addressed:	From CERL's Environmental Factors List
Applicable Building Systems:	UniFormat II Systems
Applicable Disciplines:	
Applicable Design Phases:	
Applicable Tasks:	From the Decision Process Map.
Applicability:	Code to calculate arbitrary function, Lists allowed.
Indications:	Code to calculate arbitrary function
Contraindications:	Code to calculate arbitrary function
Restrictions:	Text describing when this feature should not be used
Facilitators:	Other Design Features
Problems:	Text describing possible problems and solutions
Contradicts:	Environmental Principles and Design Features
Cases:	
Sources:	
Commonalty:	Low, Medium, High

#### Further Description of Design Feature Structure:

Title: Typically given in the form, "verbing an object with modifying phrases"

Goals: Environmental Principles

Details: Information which describes the process of how the feature can be applied, the expected outcome and rationale. This is the primary content.

Applicable Building Systems: Foundation, Basement, Superstructure (Floor and Roof Construction), Exterior Closure (Exterior walls, windows, and doors), Roofing (Coverings and openings), Interior Construction (Partitions, doors), Staircases, Interior Finishes (Wall, floor, ceiling finishes), Conveying Systems (elevators, etc.), Plumbing (includes rainwater), HVAC (includes control and instrumentation), Fire Protection, Electrical, Equipment, Furnishings, Special Construction.

Applicability: If this code fails, the design feature will not be suggested, often this value is 'All buildings' or 'All Office buildings'. There exists a lot of flexibility in specifying when features are applicable. About twenty different applicability codes are implemented.

Indications: Failure of this code will not eliminate the advice. However success will considerably boost its relevancy so that it will tend to be at the top of the list. Again, a lot of flexibility exists. Typically, items in the material list or location information is checked.

Contraindications: Success of this code, eliminates the advice.

**Facilitators:** Other design features which can be used synergistically with this one

**Contradicts:** Environmental principles and design features which this feature tends to contradict.

**Commonalty:** Low (one or a few), Medium (5 to 30 known), High (at least a few percent of all buildings of that type). Commonalty is High if a technique is commonly used, even if not for environmental reasons - e.g., a gas-fired chiller/heater may be used a lot for economic reasons.

**Example:**

**Title:** 'Including high efficiency air filtration system with prefilters and final filters'

**Goals:** 'Designing for healthy indoor air quality'

**Details:** 'The San Francisco Main Library HVAC system will include a high efficiency air filtration system with pre-filters and final filters at 30% and 85% efficiency respectively. (The 85% efficient filters remove about 65% of the 0.5 micrometer particles of the finer airborne dust.', 'SFML11.bmp', 'The Audubon filtration system includes a 35% efficiency prefilter, an 85% efficiency bag filter and 35% efficiency filters in the air handling rooms on each floor.', 'AB114.bmp', 'performance, model and supplier of filters'

**Environmental Factors Addressed:** 'Indoor Air Quality'

**Applicable Building Systems:** 'HVAC'

**Applicable Disciplines:** 'Mechanical Engineer'

**Applicable Design Phases:** 'Design Development'

**Applicable Tasks:** 'D.8'

**Applicability:** 'All buildings'

**Indications:** 'Urban'

**Contraindications:**

**Restrictions:**

**Facilitators:** 'Specifying higher than minimum ventilation rates', 'Locating HVAC system outdoor air intakes on the roof'

**Problems:** 'Can drive up HVAC energy requirements, however, in the Audubon Headquarters, this principle was used and the HVAC system is very efficient.'

**Contradicts:** 'Designing for energy efficient HVAC system'

**Cases:** 'SFLibrary', 'Audubon'

**Sources:** 'San Francisco Main Library: A Healthy Building', 'Audubon House: Building the Environmentally Responsible, Energy Efficient Office'

**Commonalty:** 'Low'

Identification of sources of the expertise is required. These sources might be information sources, books, or people. These will often come from architects and engineers who specialize in design of environmentally friendly buildings. Gathering knowledge on design features is more time consuming than gathering heuristic data on building materials. Half an hour for one simple design feature is a minimum. As much as four hours may be required for a more complex feature with accompanying figures to

further illustrate it. An average of 3 hours per feature and a requirements for 200 design features should be assumed. The data could be input by the experts in electronic format (such as a word document), or SHAI could develop an interactive design feature editor for use by experts. In either case, once the feature is input to EnvKB, it can be made available as a suggestion for other designers.

There is a special subset of the advice which deserves mention. Material Selection Advice has exactly the same structure as the design feature advice, except that it includes an additional field which is a list of links to environmentally friendly products which satisfy the advice. An example would be the suggestion to consider specifying Low VOC paint, with links to Glidden and other products. Typically, this advice is produced during Construction Documentation or from the Material Specification section of EnvKB.

### Design Consideration Relevancy Retrieval

To retrieve design considerations, conceptually, every design feature is examined against the current project. For each design feature, the five applicability fields, indications, contraindications, and cases are used to assess relevancy. The most relevant features are then displayed to the designer. Additionally, Goals and Environmental effects can be used to assess relevancy. Users have requested the ability to search by goals. If an evaluation shows large impacts with certain environmental factors, those factors can also be used to assess relevancy.

We have Relevancy Definition objects which accept the Smalltalk message, `ComputeRelevancyBetweenAdvice:CurrentProject:`. We can have different Relevancy Definitions and may attach different ones to different design consideration objects. We will have a static set of design consideration objects to be examined at each request for advice. These will be the leaf design consideration objects, which have most of their slots filled as opposed to parent objects which have little more than the advice string filled in.

Conceptually, Relevancy Retrieval loop through the set of design considerations, and for each design consideration object:

Process it further if

One of the object's Applicable Disciplines listed matches exactly the current one if a current one is defined

AND

One of the object's Applicable Design Phases listed matched the current one, exactly, if it's defined

AND

One of the object's Applicable Tasks matches at all (see below)

AND

the advice's Applicability matches at all (see below)

THEN

Compute a relevancy score with the following sum:



5 \* { if current task is undefined then 0 else  
     object's Applicable Task matches exactly the current task (1) or  
         advice is more general by one (0.5) or  
         advice is more specific by one (0.8)  
         or at least matches the first number (0.3)  
 else (-1)}  
 +  
 If one of the object's Applicable Building Systems listed matched exactly the current  
 system type then 3 else -3 else 0 if current system type is undefined  
 +  
 Object's Applicability or -5 for no match at all  
 +  
 5 if any indication applies (0 otherwise)  
 +  
 -10 \* Object's Contraindications: (currently not used)  
 +  
 5 \*  
 Cases: The maximum normalized similarity of any case in the advice's list with the current  
 project  
 +  
 5 if any of the advice's Facilitators in the current principle being used list, 0 otherwise  
 +  
 Environmental Factors Addressed:  
 +  
 Superclasses  
 +  
 Contradicts (not used)

Drop any advice with a relevancy score of 0 or less. Sort the remainder in order of decreasing relevancy.

### **Materials Information**

The materials information is organized in a hierarchy as shown in the following example. The structure for materials information is very detailed and can be presented upon request. There are two versions of Environmental data on building materials. The version delivered with EnvKB is only the information required for environmental impact evaluation and consists primarily of a vector of environmental factors. The complexity of the life-cycle assessment has been compiled away off-line, before distribution.

#### **Materials & Components**

##### **Components**

##### **HVAC Components**

##### **Chillers**

##### **1 Ton Chillers**

Carrier Model 670  
     Carrier Model 670 in Case 23  
     Trane Model 1160  
         10 Ton Chillers  
             Compressors  
                 Electrical Components  
 Materials  
     Metals  
         Steel  
             Steel Alloy 1100  
                 1000 lbs of steel alloy 1100  
             Steel Alloy 1200  
         Aluminum  
     Woods

#### Slots of Materials & Components:

Alternative Materials: Other Materials  
 Source of Information: List of Source Objects  
 Source of Material: List of Source Objects  
 Price:

Vector of hierarchical environmental factors. The vector contains both summary and detailed factors.

#### Alternatives

The original design called for a static link between conventional building materials and components and more environmentally friendly alternatives. The static version is shown here.

Conventional Material: Pointer to a material in Materials Information  
 Alternative Material: Pointer to an alternative material in Materials Information  
 Details: pictures, suppliers, model numbers  
 Environmental Factors Addressed:  
 Applicable Building Systems:  
 Contraindications:  
 Restrictions:  
 Facilitators:  
 Problems:  
 Contradicts:  
 Buildings: List of buildings/cases in which this material is used.  
 Source of Advice:  
 Uniqueness:

## **Full Material Database**

The Full Materials Database contains supporting life-cycle and process information. Its design is similar to the Phase I prototype. It is not distributed with EnvKB, but is kept off-line and used as a basis to calculate the environmental factors of each material or component.

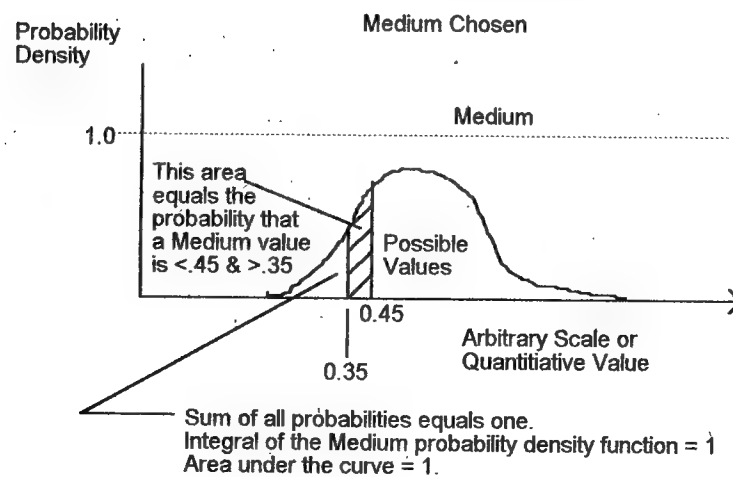
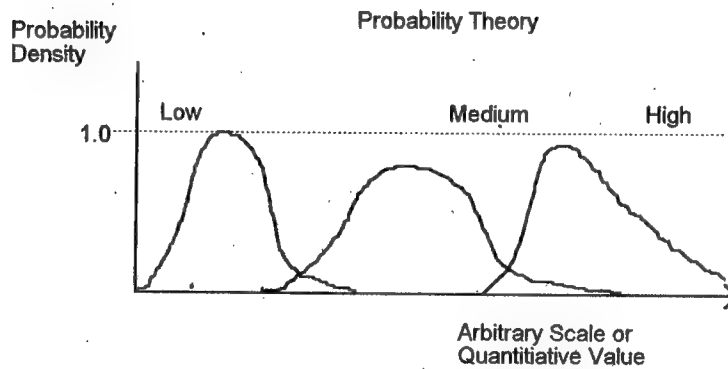
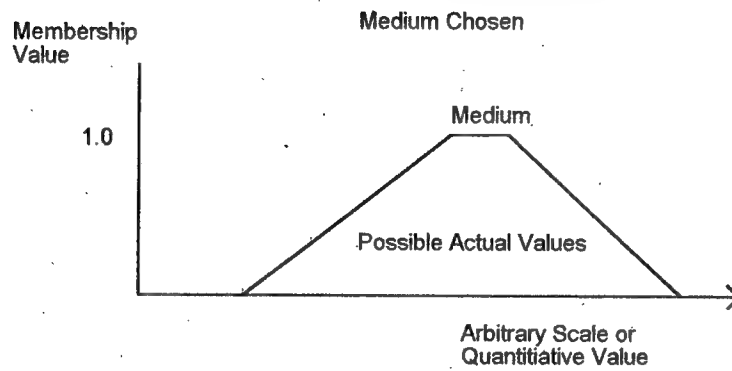
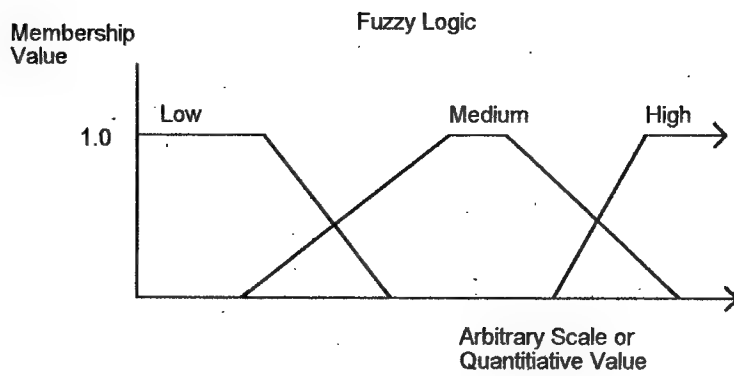
## **Evaluation**

The evaluation of building materials is currently configured to operate on qualitative or quantitative data. Using concepts of Fuzzy Logic and Probability Theory, qualitative values for environmental life-cycle impacts are converted to probability distributions as in the accompanying figure. The probability distributions are then combined to calculate the impacts for a set of materials or factors. This process creates a vector of probability distributions for each material, component or system being evaluated. Each element of the vector corresponds to one environmental factor. These probability distributions can be converted back to qualitative values for text output or the vectors can be graphed in a bar chart format for easy comparison with another option. For bar chart graphing, typically only the mean of the distribution is displayed.

The Central Limit Theorem of Probability states as the number of probability distributions are summed, the resulting distribution approaches a normal distribution. Additionally, this theorem also applies to the expert judgments. If the expert's judgment of Low, Medium, or High, is based on the combination of several factors which could also be represented as probability distributions, then his estimate will also approach a Normal distribution. This is important because Normal distributions can be easily represented and combined.

The meaning of a probability distribution is as follows. If an expert has judged a datum to be Medium (e.g. the emissions rate of a material), then the medium probability distribution shown below would be used to represent possible values. The probability that the actual datum is a certain value, (say between 0.35 and 0.45 on an arbitrary scale) is given by the area in the bottom-most graph between the two vertical lines. Notice that there is the possibility that the actual value for a Medium datum may be less than the actual value for a Low datum but that usually Medium values are greater than Low values. The probability distribution of a quantitative value (i.e. one that is known with certainty) is an infinite vertical line with an area one. Since nothing can be known exactly, a more practical representation is a very tall, narrow rectangle, with total area of one.

Adding two Normal distributions results in a Normal distribution whose mean is the sum of the two means and whose standard deviation is the square root of the sums of the squares of the standard deviations. Adding a scalar (quantitative value) to a distribution just shifts its mean. Multiplying a distribution by a scalar gives a distribution with a mean which is the product of the earlier mean and the scalar and a standard deviation which is the product of the scalar and earlier standard deviation.



The environmental impact evaluation will be based on the set of factors being developed by CERL. The data for each factor will consist of quantitative and qualitative (heuristic) values for each factor. Factors may be summed across materials when evaluating a system of several materials (e.g. embodied energy). Additionally, with SERDP guidance, detailed factors may be summed to produce summary factors (e.g. Embodied Energy may be added to use Energy to produce Total Life-Cycle Energy).

The materials should be first referenced by Masterformat number. There are about 4000 medium scope master format items. Some of those items are materials specific and some are not. On average there might be about three substantially different options (many items will have just one option from a material perspective). Therefore, there are about 12,000 building materials and assemblies to be investigated. If we state a goal, eventually, for most buildings, of trying to account for at least 80% of the environmental impacts in each environmental impact category (energy use, global atmospheric damage, etc.), then we need to only account for materials and assemblies which make up 80% of the building mass and the materials and assemblies which cause the most damage per unit of material. This strategy covers both items with a large quantity / low environmental impact per unit and items with a small quantity / high environmental impact per unit.

Many of the medium scope items will reference one or a few materials which make them up. For example, the environmental impact of a wood door is primarily the same impact as that for the kind of wood of which it is made. So many CSI items may be covered by a single material or combination of a few materials.

If three experts are each asked to state the largest environmental effects (on average about 10) and each effect requires three pieces of data, then on average there will be about 90 pieces of data for each material or assembly. That data will consist of heuristic, subjective estimates categorizing the effect has Low, Medium, or High. All unnamed effects are assumed to be None. If the environmental impact of an assembly is primarily based on the quantity of materials that make it up, the expert must simply state rough percentages of each material and we can calculate the effects based on those percentages, and the information for those specific materials.

By having three experts for each material or assembly we will be able to compare responses and flag data with wide variability. This will help ensure that such severe time restrictions are not creating the situation where the data quality is so low as to be worthless. In cases where a datum varies considerably between experts (None to Medium, None to High, or Low to High), it can be flagged for further investigation and not used until an accurate value is found. It should be again noted that it is most important to make recommendations on large differences between factors, not small differences, so that a high degree of accuracy is not required. If the identified individuals are truly experts in their materials and are currently making materials selections based on environmental factors, then these off-the-top-of-the-head estimates should be adequate for our purposes and substantially better than current practice, which is not to consider the environment at

all. The identification of true experts is critical. The better the expertise of the experts, the better the quality of the data will be.

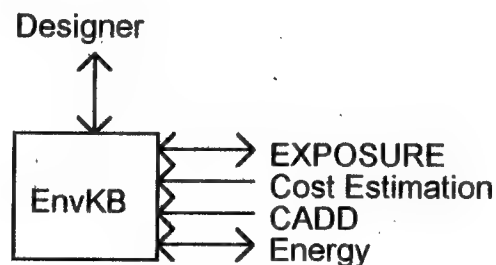
Coordinating the responses includes making sure that the experts are thinking in terms of the same scale when giving their answer. An accompanying document describes the constraints on the qualitative data in order for the data to be useful. The qualitative and quantitative data should be consistent in the sense that they both reference the same environmental factors. The only difference in the data format is that in one case the fields contain numbers, in the other case those exact same fields contain symbols (None, Low, Medium, and High).

The product from the qualitative data gathering task would be heuristic (Low, Medium, High) information on from 400 to 4000 of the most important building materials. The information would consist of approximately 10 environmental factors each described by about three pieces of data. Each piece of data will have been judged by three experts. Workshops might be an ideal method to gather this data

### **Different Modes of Operations**

EnvKB was envisioned to have at least a few different modes of operation. In the primary mode, the designer interacts with EnvKB directly. Supporting tools are used as an additional source of information.

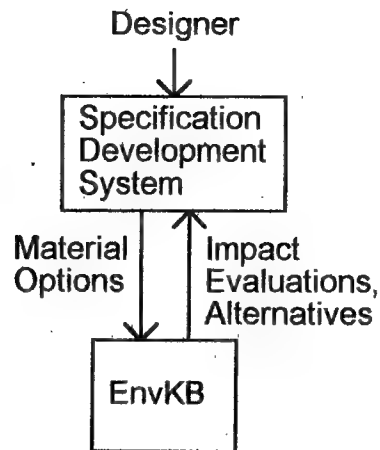
#### Primary Mode



In the other cases, the Designer may be developing a specification with a specification development tool. During the course of that development a decision between two products may arise. From within that tool, EnvKB is consulted for an environmental impact evaluation.

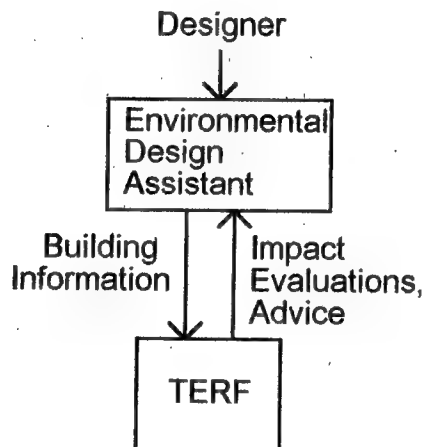


### Specification Server Mode



Finally, LBL is interested in using EnvKB as a module within their EDA system. The designer would access EnvKB's capabilities through the EDA interface.

### EDA Mode



### **3.3 Development Results**

The results of the development are given in more detail in Section 4, EnvKB functionality description. When reviewing the status of the EnvKB for designers system against what we had originally proposed (especially page 67 of the proposal, which describes what would be accomplished in the first year and in the second year), we are on or ahead of schedule in terms of effort, although assessment is somewhat complicated. We were forced to perform the work in a different order from what was originally planned, because the SERDP effort including materials research was to begin at the start of our project with initial data becoming available within about three months. We expected enough data for usability of the system by the end of the first year. Because of

funding delays and other administrative and technical problems relating to the materials research effort, materials data is only becoming available in 1995. Furthermore, enough data to make the system usable may not be available for years. The system therefore has far less material data now than we had intended, but we have worked far ahead in other areas. In fact, Impact Assessment and the Design Process Map were going to be the only modules operational at the end of the first year, yet the Design Consideration Generator and especially the CBR component are both further developed than planned. No work at all was intended on CBR in the first year. Additionally, the SERDP effort was going to be a source of environmental design knowledge, including workshops of experts. This has not yet occurred but we were able, through our own efforts, to collect considerable knowledge, design and implement more of the Consideration Generator than originally planned.

From the budget, the Designer EnvKB was supposed to be 55% done in terms of effort. The current status exceeds that because a large majority of the effort required for software development is complete. The majority of what remains is primarily information and knowledge entry. For example in the first year, we developed a second, complementary prototype, engaged in several knowledge engineering sessions, identified and collected dozens of documents, designed EnvKB (all modules), researched about 20 development tools, chose the final development tool, and implemented EnvKB for designers, which contains functionality in all areas, not just impact assessment.

We are primarily behind on entry of the materials data, which does not yet exist. But we have developed the impact evaluation system for both qualitative and quantitative data. The final list of environmental factors is still under development by CERL, so our impact evaluation system has been implemented to allow easy modification of the environmental factors list.

We are primarily ahead on the CBR component. No work was to be performed in the first year, yet we have researched cases, developed the case structure, and developed the user interface for it. Some initial cases have also been entered.

### **3.4 User Comments on EnvKB**

Several designers have seen and tried out the EnvKB software. Much of the comments addressed very detailed or specific items. There was also substantial overlap and agreement among designers on several issues, so redundancies have been eliminated. The summaries are presented here in roughly chronological order.

Overall impression: Users received EnvKB well, better than I expected. They showed genuine interest and their comments and questions showed a good understanding of what we were presenting. The idea of showing relevant cases was strongly accepted. In fact they wanted more control over the retrieval process. They seem most interested in the environmental features of cases and design principles. One wrinkle: many Corps projects will not be able to use alternative materials until those materials are in the guide spec. One

bright spot: design-build projects have lots of freedom and the Corps is using this option more. Seemed very willing to share cases if little effort is required and would even consider them advertisements. \$300 annual subscription is considered a lot for a reference. We probably couldn't charge much more than this. Therefore we need about one thousand paid subscribers to keep the project alive after Federal funding.

Very Interested in Commercial cases, not just Corps cases. The want to gain additional information from projects outside of the Corps. Designers should be able to change the weights on the retrieval factors. Dates are important: Design, Construction start, Construction finish, Occupancy Start. Retrieve cases by Principle (leaf or upper node) or Environmental Factor (Leaf or upper node). e.g. Solar Heating. MCACES is used exclusively on Corps projects but no non-Corps projects.

Reliability is very important. In place performance. How did the material or feature actually perform. Getting very simple cases back from our users would help this a lot. Just knowing which projects a material was used in and whether it caused any problems would be exceedingly helpful. EnvKB could perform the role of corporate knowledge pool where the knowledge covers all of our active users.

For example, several Sacramento buildings were supposed to be Green (probably energy efficient) but were Sick buildings instead. Cases as lessons learned. e.g. negative examples.

Good Resource - Corps Award for good Environmental Design (chosen by A/Es as environmentally conscious). Air Force has similar program. Also Presidential Design Awards. Murry Guyer at Headquarters would know about Corps one. There is a brochure associated with each building receiving an award. Gary Headly at Brooks AFB would know about the Air Force program.

AutoCADD on the rise (all were users), Intergraph is waning. Almost all users are AutoCADD now. Blast is required but they prefer Trane's. Title 24 is an issue. All projects do energy budgets and life-cycle costing. Energy Consumption is a big issue. Army gives out awards based on beating the budget which is based on size, type and location. Get Energy budget numbers from Steve Slinker. Vatican Hospital in St. Louis is a 250-bed passive solar facility (good case?); has a clinic facility attached (Doc in Box). Seattle district has done lots of passive solar stuff (about 8 years ago). Utility companies all have programs. Check with each one including PG&E. e.g. Southern CA Edison did a 330-unit housing project using a water-source heat pump. Ted Gold at Southern Cal Edison would know about them.

Current Corps work is mostly Army Barracks (new Barracks, like dormitories). Second are vehicle maintenance shops. Third was family housing. Where soldiers live and work is important. Admin facilities are low priority. Family housing is design-build, more of an opportunity, Army owns the housing. Both Army and AF are design-build. Design build: choice of materials from the commercial community. Government is doing more design-builds (Admin, child-care, hospitals).

Availability and cost of materials is critical.

Can't specify a supplier. Material must have 3 (or maybe 2) sources. Except for the following example: 0-VOC paint has 1 supplier, Low VOC paint has two suppliers, specify < 50 VOC paint: three suppliers since  $0 < 50$ .

They need top-down directives to use materials or consider environment more strongly. Huntsville is the guardian of the Spec. Users could send lessons learned back. Value Engineering team (Savannah) looks at design, could be a place to put in environmental factors.

Designers must be able to work on the same project in parallel. They will need to see some of each others work, but not all. Private/Public areas? Designer works in private area. When he wants others to see something he sends it to the public area. Architect starts the project, then everyone works in parallel.

Coastal regions different - salt spray/corrosion. Smog in LA can be a similar factor. Reducing renovation waste seen as a benefit - customers want more flexibility, to be able to move walls for instance. Browse solar cases or look at similar cases for all environmental principles: both are important. ITS concept interesting but no it would not be used.

Architect won't specify a new technique without a fall-back like it was used successfully in three similar applications.

One designer did 90-95% non-Corps work (25-man architectural firm). Non-Corps projects: did cost estimates on spreadsheet, had own master spec (5-6"), used AutoCADD.

Quarterly updates of cost data seemed about right to them. Recycled material costs drop over time for example.

Adjust for old project costs based on construction cost index (different from general inflation). A request: Charge small firms less, probably not if on CD-ROM (big companies will have to buy more). Put on a bulletin board and charge per minute maybe. Problems with graphics over phone lines.

Willing to share cases, one guy shares with Dodge now, will depend on time. We could probably use whatever they gave us, especially if they added an update after construction/occupancy that no problems were encountered. They said that they would consider their own cases as a form of advertisement.

Graphics are useful, especially if could capture details to put in their own drawings. Could maybe get such details from manufacturers. Also could get language from manufacturers to be put into specs.

Must be able to print out information.

They saw two uses:

Early: get ideas from similar cases

Construction Documents Phase: pick out a single item, e.g. very efficient glazing from a hospital for use in an office building (notice not similar buildings)

Might need to narrow search. Glazing produces 1500 matches so ask for more specifics. Also we can prioritize the list in term of similarity.

Virtual building was not wanted. A checklist of possibilities seemed better (which is in effect what our principle hierarchy is)

Cost/Square foot for different features, like filtration, would be useful

Reference sources like Sweet's like "this information is in Sweet's Source". A particular product is always the end result of design. We're on the front end and Sweet's is at the back end.

Corps work: Designers still have a choice if guide doesn't dictate

" " : Designers set shape generally

" " : Check points - check with customer, keep from deviating, try to satisfy

Everyone uses the same design process

May skip some in simple ones

May have more iterations in more complex ones

The earlier environment can be included in the design process the better, budget more flexible up front.

Present client with alternatives, let him decide.

Including products in guide spec is not that big a deal but they will be tested. Guide spec lists applicable standards at the beginning.

Individual systems should be cases. HVAC system should be retrievable based on loads for example.

A number of items are common knowledge - energy stuff, lighting, schematic design. Many are also unknown - IAQ, Construction Documentation phase. Also has value as an educational device. More value to younger designers. As it becomes more developed it will be more valuable to experienced designers. Windows interface is a good idea.

Interdisciplinary perspective is important.

Need advice at construction documents and schematic design (both ends) with some additional Design Development to it filled out. Expand rationale discussion. Considerations may need a purpose statement. More development to support the conveying of knowledge (instead of a particular physical manifestation or application of that knowledge). Deliberate on what pieces of information convey knowledge. More explicit replication of design process. Presentation of supporting information - decision process to let user make their own decision process. Justifications needed. Display logic track. Run advice through an Architect and expert panel. Need many options presented. Most of the time could be better descriptions, more accurate terminology, better developed thought, more support. An issue often brings up more issues - close loops or at least mention issue. Instances of advice are good.

Optimizing acoustic environment is an environmental goal

Re-introduce Olgyay : Design with Climate and Lynch into the design process.

Copy items to current project and print out report.

Related suggestions don't pop out at you.

Viewer ought to be aware of many things all simultaneously, highlight important aspects.

More case studies - more modular approach.

Need: "don't show this again for this project"

CSI spec data sheet - for individual products, get for alternative materials and state "according to the manufacturer".

System option comparisons are important

Expected life is in repair and Maintenance Software (Skip Neely). Lifetime -from manufacturers - (manufacturers claim/service life/replacement cycle). Show lifetime factors then do the calcs.

Some things aren't bar charts but narratives. Not always bar charts to compare (NLG?). Bar charts on top, narrative underneath.

What protocol does a designer use to choose which material

Balancing trade-offs is important - small use of bad thing could be balanced by less of something else.

Project Evaluation then grab advice which addressed worst evaluated environmental factors.

Add field telling Engineer how to validate that advice worked - like run a DOE run or lighting analysis or monitor in place performance

NFPA Life Safety, Chapter 101 for occupancy types

IAQ is a primary concern - problems with one project. Municipalities and other clients getting more IAQ conscious. They specify low VOC paint and low-emitting particle board.

Need a glossary (e.g. VOCs).

Explain IAQ and source-sink phenomena. Knowing about absorption and re-emitting allows smarter construction task scheduling.

Guide specs for products

User would use Sweet's to pick three acceptable products, could then do an environmental evaluation to choose from among those three.

Windows UI is good.

### **3.5 EXPOSURE Interface**

The primary reasons for interfacing with the EPA's EXPOSURE program are to use its output in the environmental evaluation of a building and potentially trigger IAQ advice. EXPOSURE calculates both the concentration of pollutants in the air and the exposure of occupants based on their activity patterns. The program requires six input files which EXPOSURE assembles by providing an editing capability to the user. The .bld file describes general features of the building. The .rom file describes the dimensions, volume, air flows, sources, and sinks of each room. The .sor and .sin files describe the characteristics of individual sources and sinks, respectively. The .hva file describes the air flow characteristics of the HVAC system and the presence of any air cleaners as well as sources or sinks in the HVAC system. Finally, the .act file describe an occupancy profile for each occupant. It describes how long he spends in each room. EXPOSURE calculates two output files. The .res files gives the pollutant concentration for each room

for each time step. The .exp file gives the results of the exposure calculation for each occupant for each time step. None of the above files (.bld, .rom, .sor, .sin, .hva, .act, .res, .exp) are in text format. However, EXPOSURE contains an option, to file the concentration or exposure calculations, which converts either of the two output files into a text format. It would then be straight-forward to parse and read in these time history files, since they have a simple format. Each record in a .dat file is of the same format. The first item in the record is the time. Every other field in the record contains the concentration (or exposure) for that time. For concentration outputs, the fields correspond to concentration inside each room and the HVAC system. For exposure outputs, the fields correspond to exposures of each occupant. Each record is terminated with a carriage return. Primarily, we would read the concentration output and use it in the building's environmental impact evaluation and to assess the relevancy of IAQ advice.

Another possibility, would be to generate or partially generate the input files required by EXPOSURE, if EnvKB already has some of the relevant building information, to prevent the user from having to enter it again in EXPOSURE. We would need to work with Leslie Sparks of the EPA's Air and Energy Engineering Research Laboratory, to determine the exact format for those input files. Additionally, if we have all the information required by exposure, we could possibly generate complete input files and call EXPOSURE to produce output files. This would require some simple modification of EXPOSURE, to allow it to be called programmatically.

### **3.6 Energy Analysis Software Interface**

Version 2.0 of the Designer EnvKB will be able to electronically read in results produced by the DOE-2 energy analysis program. DOE-2 simulates the performance of a building, hour by hour, through a climate trace for a particular year and city. From this simulation it calculates energy use. Designer EnvKB will be able to read preformatted summary reports output by DOE-2. The primary purpose served by reading DOE-2 output is to use energy use information for environmental evaluation and to trigger advice relating to energy consumption. The two primary DOE-2 reports for this purpose are PS-B, "Monthly Peak and Total Energy Use," and BEPD, "Estimated Building Energy Performance." Both of these reports give total energy use and a matrix breakdown by type (electricity, natural gas, etc.) and another dimension. For the former, that dimension is month and for the latter that dimension is use type (space heat, space cool, lights, etc.). Parsing these reports for the desired information is straight-forward due to their columnar format.

Another DOE-2 report with interesting information is LV-D, "Details of Exterior Surfaces" which contains average U-values for walls and windows. This information could be used to trigger energy related advice based on those U values and building geographical location. Report SS-A, "System Monthly Loads Summary," provides monthly heating and cooling loads, which could be used in conjunction with LV-D to trigger advice.



Report SV-A, "System Design Parameters," provides ventilation rates to each space. Combined with the input BDL (Building Description Language) files, which provide the volume of each space, these can be used as a basis for performing EXPOSURE runs and triggering IAQ advice.

### **3.7 CADD Integration**

The primary purpose of integrating with CADD software is to get the components and material quantities (schedules, bill of materials, volumes, areas) of a building from the CADD system. A secondary purpose is to allow the display of CADD drawings for illustration of design features or display of details which can be copied to the user's actual construction documents files. SHAI investigated several CADD packages and narrowed consideration down to AutoCADD and InterGraph, which are the two systems sanctioned by the DOD. AutoCADD for windows is becoming the most widely used, so we concentrated on it. By developing EnvKB as a windows application, we are facilitating the interface to all Windows programs, especially AutoCADD. AutoCADD users have commented that EnvKB, as a Windows program, has a similar "look and feel" to AutoCADD, which makes its use easier.

After investigating the way in which AutoCADD is used by designers, we have determined that material quantities and components cannot be practically extracted from CADD files. Not enough standardization exists in the format of those files. However, there are several third party cost estimating, quantity take-off, bill of materials, and schedule producing programs which operate with AutoCADD. SHAI is investigating twenty such packages. The best way to interface to and get the desired information from AutoCADD appears to interface with one or more of these third party programs. The interface would be similar to the interface to MCACES. User would use AutoCADD and the third party tool to develop a list of materials or components. EnvKB would then electronically read this list from the data file created by the third party tool.

There are also several lighting design and analysis packages which interface with AutoCADD, to which EnvKB may interface. These include Auto-Site, Genesys, LightCAD, SHADOW, Light Works, and AGI. We are currently investigating these products for their potential benefit to EnvKB.

## **4.0 Designer EnvKB Description**

### **Environmental Knowledge Base (EnvKB) System Description**

The Designer EnvKB offers suggestions and decision support to a facility designer to reduce the environmental impact of the facility throughout its life-cycle and throughout the life-cycle of its components. The Designer EnvKB software implementation is at its first release. It already includes capabilities to evaluate and compare the environmental impacts of building materials, offer environmental design suggestions, retrieve relevant cases of good environmental design, integrate with the CERL Design Process Map and MCACES cost estimation tool, a database of environmental alternative building materials, and user interface to enter the designer's current project and access these capabilities. To become operational, it is primarily lacking building material and assembly environmental data and knowledge.

The second release of Designer EnvKB is scheduled for August 31, 1995 with a beta version one month earlier. To become operational, this version must include more data and knowledge. Software enhancements include integration with CADD, energy analysis, and IAQ exposure software. Expanded design suggestion and case retrieval will be included to handle the greater quantity of environmental knowledge and impact data on building materials and assemblies. The Design Process Map will be expanded to include life-cycle connections and environmental factors. The third release of Designer EnvKB is Scheduled for February 28, 1996, with a beta version released one month earlier. The content of that release will primarily be based on user comments and requests generated from use of the second release.

#### **Evaluation**

The evaluation of building materials is currently configured to operate on qualitative or quantitative data. The user is shown a bar chart of the environmental impacts of the material, component, system, or building. The environmental impact evaluation will be based on the set of factors being developed by CERL. The data for each factor will consist of quantitative and qualitative (heuristic) values for each factor.

The materials should be first referenced by Masterformat number. There are about 4000 medium scope master format items. Some of those items are materials specific and some are not. There are about substantially different options (many items will have just one option from a material perspective).

## Design Suggestions

Designer EnvKB contains a set of environmental design features, most of which are associated with a specific case. Each environmental design feature includes knowledge as to its own applicability to different projects. After the user has entered information on his current project, each design feature is individually assessed for its relevancy to the current project and the most relevant ones are displayed. Each design feature also includes several links. These links connect the feature to other features which aid its goal, to principles it is trying to accomplish, to environmental factors it is addressing, to environmental principles it is in conflict with, to cases which utilize it, and to the sources which described the feature.

The information stored for each design feature includes a title in the form of a suggestion, a description of the feature, the process by which it should be incorporated into the design, the rationale, the environmental factors it addresses and the possible magnitude of that impact, information regarding when the feature is applicable, problems and restrictions associated with the design feature, projects in which it was used, other design features which facilitate this features application, and where in the design process the feature should be considered. The structure is described below, where anytime a plural word is used, more than one value can be present. An example follows.

Title:	One line description.
Goals:	Principles above this one in the goal hierarchy.
Details:	Text or text, picture, or other media files,
Environmental Factors Addressed:	From CERL's Environmental Factors List
Applicable Building Systems:	UniFormat II Systems
Applicable Disciplines:	
Applicable Design Phases:	
Applicable Tasks:	From the Decision Process Map.
Applicability:	Code to calculate arbitrary function, Lists allowed.
Indications:	Code to calculate arbitrary function
Contraindications:	Code to calculate arbitrary function
Restrictions:	Text describing when this feature should not be used
Facilitators:	Other Design Features
Problems:	Text describing possible problems and solutions
Contradicts:	Environmental Principles and Design Features
Cases:	
Sources:	
Commonalty:	Low, Medium, High

### Further Description of Design Feature Structure:

Title: Typically given in the form, "verbing an object with modifying phrases"

Goals: Environmental Principles

Details: Information which describes the process of how the feature can be applied, the expected outcome and rationale. This is the primary content.

Applicable Building Systems: Foundation, Basement, Superstructure (Floor and Roof Construction), Exterior Closure (Exterior walls, windows, and doors), Roofing (Coverings and openings), Interior Construction (Partitions, doors), Staircases, Interior Finishes (Wall, floor, ceiling finishes), Conveying Systems (elevators, etc.), Plumbing (includes rainwater), HVAC (includes control and instrumentation), Fire Protection, Electrical, Equipment, Furnishings, Special Construction.

Applicability: If this code fails, the design feature will not be suggested, often this value is 'All buildings' or 'All Office buildings'. There exists a lot of flexibility in specifying when features are applicable. About twenty different applicability codes are implemented.

Indications: Failure of this code will not eliminate the advice. However, success will considerably boost its relevancy so that it will tend to be at the top of the list. Again, a lot of flexibility exists. Typically, items in the material list or location information are checked.

Contraindications: Success of this code, eliminates the advice.

Facilitators: Other design features which can be used synergistically with this one

Contradicts: Environmental principles and design features which this feature tends to contradict.

Commonalty: Low (one or a few), Medium (5 to 30 known), High (at least a few percent of all buildings of that type). Commonalty is High if a technique is commonly used, even if not for environmental reasons - e.g., a gas-fired chiller/heater may be used a lot for economic reasons.

### Case Retrieval

EnvKB will support a case base, or case studies, of environmentally good facilities. The experts, in written format, could describe the environmentally friendly design features of their buildings and the process of applying these features to other situations as well as the general description and context for the building such as its design, function, location, etc. These design features could take the form described above or could be environmentally good material or component choices along with the supporting rationale. The cases will be input to EnvKB and become part of the case base, to be presented to other designers when deemed relevant. The design features and material selections may become part of the advice generator and will be suggested to the user when relevant as described above. A workshop would be an ideal approach to the gathering of environmentally friendly case studies.

After entry of current project information, the system can assess the similarity of the stored cases of good environmental design and display the most relevant. With each case is descriptive information which sets the context for the design. Each case includes environment design features (described above), and the list of environmental materials or components used. Cases may be divided into sub-cases, especially by systems. For example the HVAC system of the Audubon building would be part of the Audubon case and a case in its own right.

Cases have the same structure as user projects, though the emphasis of the information content is different. Each case includes a list of material choices, a list of design features, descriptions of the site and building, occupancy type, location information (longitude, latitude, altitude, urban or rural, biome, etc.), whether it is a renovation, and construction type. Cases may also contain a list of systems, with each system having this same kind of structure.

Because user projects have the same structure as cases, assessing similarity is simplified. For each case, every item of the case structure can be matched to the corresponding item in the user's project. The relative importance of each item is stored in a similarity definition. A different similarity definition can be stored with each case if desired, for maximal flexibility.

### Design Process Map

CERL has developed a Design Process Map which describes, graphically, the process of facility design. Designer EnvKB includes an interactive version of this graphical map for users to explore and also to specify their current task, which is used in making design suggestions. The Design Process Map will be expanded to include life-cycle connections and environmental factors. These connections can be used to further tailor the advice and to also inform the designer as to the most relevant environmental factors to keep in mind at this particular task.

### Alternative Products

Designer EnvKB includes over 700 products featured for their environmental aspects. This database is used to retrieve alternative products for the designer to consider. These products are also linked to design advice, when appropriate. The products are indexed by CSI number and can be further sorted by number of matching keywords.

### MCACES Integration

EnvKB can read MCACES report files to get the list of building components and materials and their quantities. We are investigating the use of MCACES as a source of pricing data as well. EnvKB can also read ASCII files in a format easily exported from spreadsheets.

## **5.0 Operator EKBS Description**

The Operator EnvKB will be released September 30, 1995, with beta versions three months and one month earlier. It will suggest methods of operation to reduce environmental impact of building operations including energy use, waste produced, resources consumed, and indoor air quality. It will contain a database of products which can be used to reduce the facility's environmental impact. It will also contain a link to the Designer EnvKB so that if the facility designer used Designer EnvKB during the design process, his intentions as regards the environment are available to the operator and used as a basis for further suggestions. The current operator prototype contains a small number of considerations and several environmental products.

## **6.0 Builder EKBS Description**

The Builder EnvKB will be released March 31, 1996, with beta versions three months and one month earlier. It will contain much of the same functionality as the Designer EnvKB, but aimed at a different audience. It will include capabilities to evaluate and compare the environmental impacts of building materials and components, offer environmental construction suggestions, retrieve relevant cases of good environmental construction practices, a database of environmental alternative building materials, and user interface to enter the builder's current project and access these capabilities. It will also contain a link to the Designer EnvKB so that if the facility designer used Designer EnvKB during the design process, his intentions as regards the environment are available to the builder and used as a basis for further suggestions. Work has not yet begun on the Builder EnvKB.